

PARALLEL PROCESSING SYSTEM BY OS FOR SINGLE PROCESSORS
AND PARALLEL PROCESSING PROGRAM

BACKGROUND OF THE INVENTION

5 1. Field of the Invention

The present invention relates to a parallel processing system by a multiprocessor and, more particularly, to a parallel processing system by an OS for single processors capable of operating an OS for single processors and an existing application for single processors on a multiprocessor to enable the application to realize parallel processing by a multiprocessor, and a parallel processing program.

10 2. Description of the Related Art

15 In data processing devices such as mobile terminals including a mobile phone and a mobile PC, an operating system for single processors (hereinafter referred to as an OS for single processors) and an application for single processors (hereinafter simply referred to as an application) are basically executed on 20 a single processor.

25 Under these circumstances, when using the above-described application without modification on a multiprocessor basis, the application should be executed on an OS for multiprocessors in place of the above-described OS for single processors.

Among such systems which controls execution of an

OS for multiprocessors and an application on such a multiprocessor system as described above are, for example, the conventional art disclosed in Japanese Patent Laying-Open (Kokai) No. 3-257652 and Japanese Patent Laying-Open (Kokai) No. 3-113563.

Japanese Patent Laying-Open (Kokai) No. 3-257652 (Literature 1) discloses a method of controlling interruption between the respective processor elements in a multiprocessor system composed of a plurality of processor elements.

Japanese Patent Laying-Open (Kokai) No. 3-113563 (Literature 2) discloses a method of scheduling processes to be assigned to a plurality of processors in a multiprocessor system.

On the other hand, Japanese Patent Laying Open (Kokai) No. 2003-058515 (Literature 3) discloses a method of executing an individual process in a plurality of processor elements.

When operating an existing application on an OS for multiprocessors as in conventional art, however, the OS for multiprocessors provides services for multiprocessors even when the application uses only one among a plurality of processors, or continues processing exclusive of other processor even when no other application operates, so that these extra processing causes overheads.

While modifying the above-described application

to be adaptable to multiprocessors will eliminate the above-described problem, another problem will be produced of requiring considerable labor and costs for modification.

5 On the other hand, when an application is used without modification on an existing OS for single processors, it is highly demanded that an existing application should be operated without modification on a multiprocessor.

10 Moreover, communication between processes in parallel processors needs a function of sharing communication data and a mechanism for conducting sleep and wake-up of a processor, which functions have been conventionally realized being mounted on a kernel level 15 of an OS. In other words, communication between processes in parallel processors requires an OS for parallel processors. Here, communication between processes represents synchronization of processing and data transmission and reception between the processes.

20 Accordingly, the foregoing described simple parallelization of an OS for single processors which operates the OS for single processors on each processor of a multiprocessor enables communication between processes in the same processor by the function of the 25 OS for single processors, while enabling no communication between processes in different processors.

 Literature 3, for example, discloses nothing

about a method of inter-process communication between different processors.

Although not by the original function of an OS for single processors but by using a network, for example, communication between processes in different processors is enabled, a delay in processing of network communication will cause an overhead to make parallel processing by a multiprocessor meaningless.

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SUMMARY OF THE INVENTION

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An object of the present invention is to provide a parallel processing system by an OS for single processors which operates an OS for single processors and an existing application for single processors on a multiprocessor without modifying them to enable the existing application to realize parallel processing by the multiprocessor, and a parallel processing program.

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Another object of the present invention is to provide a parallel processing system by an OS for single processors which operates an OS for single processors and an existing application on a multiprocessor without modifying them, as well as enabling units of work of the application to be controlled synchronously or asynchronously between processors, and a parallel processing program.

A further object of the present invention is to provide a parallel processing system by an OS for single

processors which enables communication between processes in parallel processors even on an OS for single processors without requiring an OS for multiprocessors by the provision of an inter-process communication function on a user level, and a parallel processing program.

According to the first aspect of the invention, a parallel processing system by an OS for single processors which operates an OS for single processors and an application on a multiprocessor, and controls a unit of work that can be parallelized within the application operating on one processor as a new unit of work on other processor, thereby conducting parallel processing by the multiprocessor with respect to the application.

According to another aspect of the invention, a parallel processing system by an OS for single processors which operates an OS for single processors and an application on a multiprocessor, the multiprocessor being logically divided into two groups of a first processor side and a second processor side, and controls a unit of work that can be parallelized within the application operating on a processor on the first processor side as a new unit of work on a processor on the second processor side, thereby conducting parallel processing by the multiprocessor with respect to the application.

According to another aspect of the invention, a parallel processing system by an OS for single processors which operates an OS for single processors and an application on a multiprocessor, the 5 multiprocessor being divided into two groups of a first processor side and a second processor side, operates the OS for single processors and the application on a processor on the first processor side, and controls a unit of work that can be parallelized within the 10 application as a new unit of work on a processor on the second processor side, thereby conducting parallel processing by the multiprocessor with respect to the application.

According to another aspect of the invention, a 15 parallel processing program by an OS for single processors, comprising the functions of operating an OS for single processors and an application on a multiprocessor, and controlling a unit of work that can be parallelized within the application operating on one 20 processor as a new unit of work on other processor to conduct parallel processing by the multiprocessor with respect to the application.

According to another aspect of the invention, a 25 parallel processing program by an OS for single processors, comprising the functions of operating an OS for single processors and an application on a multiprocessor, and on a system in which the

multiprocessor is logically divided into two groups of a first processor side and a second processor side, controlling a unit of work that can be parallelized within the application operating on a processor on the 5 first processor side as a new unit of work on a processor on the second processor side to conduct parallel processing by the multiprocessor with respect to the application.

According to another aspect of the invention, a 10 parallel processing program by an OS for single processors, comprising the functions of operating an OS for single processors and an application on a multiprocessor, on a system in which the multiprocessor is logically divided into two groups of a first 15 processor side and a second processor side, operating the OS for single processors and the application on a processor on the first processor side, and controlling a unit of work that can be parallelized within the application as a new unit of work on a processor on the 20 second processor side to conduct parallel processing by the multiprocessor with respect to the application.

Other objects, features and advantages of the present invention will become clear from the detailed description given herebelow.

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BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood more

fully from the detailed description given herebelow and from the accompanying drawings of the preferred embodiment of the invention, which, however, should not be taken to be limitative to the invention, but are for explanation and understanding only.

5 In the drawings:

Fig. 1 is a block diagram showing a structure of a parallel processing system according to a first embodiment of the present invention;

10 Fig. 2 is a diagram for use in explaining operation of activating parallel processing by a parallel processing unit in the parallel processing system according to the first embodiment;

15 Fig. 3 is a diagram showing arrangement of a message for giving a command in parallel processing activation by the parallel processing unit of the parallel processing system;

20 Fig. 4 is a diagram for use in explaining operation of an OS service unit to be conducted in response to a file access command from a task on a second processor side in the parallel processing system according to the first embodiment;

25 Fig. 5 is a diagram for use in explaining operation executed in response to a file access command from a sequential task on a first processor side;

Fig. 6 is a block diagram showing an internal structure of a control processing relay unit in the

parallel processing system according to the first embodiment;

5 Fig. 7 is a diagram for use in explaining processing operation of the control processing relay unit in the parallel processing system according to the first embodiment;

10 Fig. 8 is a diagram for use in explaining signal notification processing operation by a proxy unit in the parallel processing system according to the first embodiment;

Fig. 9 is a block diagram showing a structure for realizing cooperative operation between tasks on the second processor side in the parallel processing system according to the first embodiment;

15 Fig. 10 is a diagram for use in explaining cooperative operation between tasks on the second processor side in the parallel processing system according to the first embodiment;

20 Fig. 11 is a diagram for use in explaining a case of operating an application on a mobile terminal of a multiprocessor as an example of application to the parallel processing system;

25 Fig. 12 is a block diagram showing a structure of a parallel processing system according to a second embodiment of the present invention;

Fig. 13 is a diagram for use in explaining operation of synchronously activating parallel

processing of processes in the parallel processing system according to the second embodiment;

5 Fig. 14 is a diagram for use in explaining operation of asynchronously activating parallel processing of processes in the parallel processing system according to the second embodiment;

10 Fig. 15 is a block diagram showing an internal structure of a control processing relay unit in the parallel processing system according to the second embodiment;

15 Fig. 16 is a diagram for use in explaining processing operation of the control processing relay unit in the parallel processing system according to the second embodiment;

20 Fig. 17 is a block diagram showing a structure of a parallel processing system according to a third embodiment of the present invention;

25 Fig. 18 is a diagram for use in explaining operation to be executed when a process in a processor conducts semaphore-up or -down by using a semaphore system by means of an inter-process communication unit in the parallel processing system according to the third embodiment;

30 Fig. 19 is a diagram for use in explaining operation to be executed when a process in a processor conducts semaphore-down by using the semaphore system by means of the inter-process communication unit in the

parallel processing system according to the third embodiment;

Fig. 20 is a diagram for use in explaining operation to be executed when semaphore-up is conducted between processes in the same processor by using the semaphore system by means of the inter-process communication unit in the parallel processing system according to the third embodiment;

Fig. 21 is a diagram for use in explaining operation to be executed when semaphore-up is conducted between processes in different processors by using the semaphore system by means of the inter-process communication unit in the parallel processing system according to the third embodiment;

Fig. 22 is a diagram for use in explaining operation to be executed when a process in a processor receives a message by using a message queue system by means of the inter-process communication unit in the parallel processing system according to the third embodiment;

Fig. 23 is a diagram for use in explaining operation to be executed when a process in a processor receives a message by using the message queue system by means of the inter-process communication unit in the parallel processing system according to the third embodiment;

Fig. 24 is a diagram for use in explaining

operation to be executed when a process in a processor
transmits a message by using the message queue system by
means of the inter-process communication unit in the
parallel processing system according to the third
5 embodiment;

Fig. 25 is a diagram for use in explaining
operation to be executed when message transmission and
reception is conducted between processes in the same
processor by using the message queue system by means of
10 the inter-process communication unit in the parallel
processing system according to the third embodiment;

Fig. 26 is a diagram for use in explaining
operation to be executed when message transmission and
reception is conducted between processes in different
15 processors by using the message queue system by means of
the inter-process communication unit in the parallel
processing system according to the third embodiment;

Fig. 27 is a diagram for use in explaining a
specific example of inter-process communication by using
20 the semaphore system and the message queue system in the
parallel processing system according to the third
embodiment;

Fig. 28 is a diagram for use in explaining
display contents on a browser screen in the specific
25 example shown in Fig. 27; and

Fig. 29 is a block diagram showing a structure of
a parallel processing system according to a fourth

embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The preferred embodiment of the present invention
5 will be discussed hereinafter in detail with reference
to the accompanying drawings. In the following
description, numerous specific details are set forth in
order to provide a thorough understanding of the present
invention. It will be obvious, however, to those skilled
10 in the art that the present invention may be practiced
without these specific details. In other instance, well-
known structures are not shown in detail in order to
unnecessary obscure the present invention.

In the parallel processing system of the present
15 invention, parallel processing is executed on a
multiprocessor by adding a mechanism for asking for
processing with respect to a plurality of processors and
a mechanism for protecting a critical section in the
provision of OS services to a plurality of processors
20 without adding any modification to a conventional OS for
single processors.

In the following, preferred embodiments of the
present invention will be described in details with
reference to the drawings.

25 Fig. 1 is a block diagram showing a structure of
a parallel processing system according to a preferred
embodiment of the present invention.

As shown in Fig. 1, the parallel processing system according to the present embodiment includes a multiprocessor composed of a plurality of processors (CPU) P0 to Pn (n is an integer not less than 1) connected through a system bus 91, which is logically divided into two groups of a first processor side 10 and a second processor side 20, with an OS 30 for single processors mounted which operates on the processor P0 on the first processor side 10 and parallel processing units 40P0 to 40Pn for conducting parallel processing and OS service units 50P0 to 50Pn for processing OS service mounted on the processor P0 on the first processor side 10 and the processors P1 to Pn on the second processor side 20, respectively. Connected to the system bus 91 are a main storage device 92 as a shared memory shared by the respective processors P0 to Pn and an external storage device 93 such as a disk device.

The above-described multiprocessor may be structured not only to include a plurality of processors of the same kind but also to include a plurality of processing devices of different kinds such as a DSP and a security engine.

Between the first processor side 10 and the second processor side 20, a control processing relay unit 60 is uniquely provided for transmitting and receiving a control signal and data and a proxy unit 70 is provided on the first processor side 10 through which

the OS 30 for single processors communicates with a task executed on the second processor side 20.

The processor on the above-described first processor side 10 does not necessarily exist as a single processor but exist as a plurality of processors. It is possible, for example, that two processors are provided on the first processor side 10 and each is mounted with a different OS for single processors.

Used as the OS 30 for single processors activated by the processor on the first processor side 10 is an existing OS. For example, a real time OS and a UNIX (R) OS are used without modification.

Task used in this specification represents a unit of work for conducting parallel processing of a process and a thread on a UNIX (R) OS, a task on a real time OS and the like.

In the parallel processing system according to the present embodiment, an application operates on the OS for single processors on the first processor side 10 and among the units of work of the application, a task (sequential task) which can not be parallelized is processed by the processor P0 on the first processor side 10 and a task which can be parallelized within the application is created as a new task on the second processor side 20 and parallel-processed.

The parallel processing unit 40P0 and the parallel processing units 40P1 to 40Pn have a function

of performing creation, activation, stop, termination and deletion of a task and other control related to tasks. Here, the parallel processing unit 40P0 of the first processor side 10 conducts such processing as creation, activation, stop, termination and deletion of a task through the control processing relay unit 60 with respect to the parallel processing units 40P1 to 40Pn of the respective processors P1 to Pn on the second processor side 20. As to signal notification, it is processed bidirectionally from both the parallel processing unit 40P0 and the parallel processing units 40P1 to 40Pn.

The OS service unit 50P0 and the OS service units 50P1 to 50Pn have a function as an interface for conducting various kinds of accesses to an external apparatus and control of the same and an interface for conducting various kinds of accesses to a resource shared among tasks and control of the same.

The control processing relay unit 60 is a unit for transmitting and receiving a control signal and data between the first processor side 10 and the second processor side 20 and used in control between a plurality of tasks processed in parallel to each other by a plurality of processors.

The proxy unit 70 is associated with tasks (a part or all of them) executed on the second processor side 20 and is mounted for signal notification

(notification of various kinds of control signals for controlling tasks) between the task on the second processor side 20 and the OS 30 for single processors.

5 In the following, detailed description will be made of operation of thus structured parallel processing system according to the present embodiment with reference to the drawings.

10 Assume here that the application operates on the OS for single processors on the first processor side 10 and among the units of work of the application, a unit to be processed by the processor P0 on the first processor side 10 is defined as a sequential task ST and a unit which is a task that can be parallelized within the application and is parallel-processed by the second processor side 20 as tasks PT-1 to PT-n is defined as a parallelization task PT.

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20 First, description will be made of operation of activating parallel processing by the parallel processing units 40P0 and 40P1 to 40Pn with reference to Figs. 2 and 3.

25 (1) In a case of activating the parallelization task PT on the first processor side 10 as any of the tasks PT-1 to PT-n on the second processor side 20, command the parallel processing unit P40 to create any of the tasks PT-1 to PT-n as a unit of work to be activated on the second processor side 20.

Commands from the parallel processing unit 40P0

and the parallel processing units 40P1 to 40Pn include, for example, create (task creation), delete (task deletion), activate (task activation), terminate (task termination), signal (signal command), etc. Among those 5 commands, create (task creation), delete (task deletion), activate (task activation) and terminate (task termination) are commands sent from the first processor side 10 to the second processor side 20 and signal (signal command) is sent bidirectionally both from the first processor side 10 and the second processor side 20. 10

These commands are made by a message as shown in Fig. 3. More specifically, by transmitting to the parallel processing unit 40P0 a message composed of a request contents 201 indicative of the contents of a 15 request (task creation in this case), a processor number 202 designating the processor P1 ~ Pn on the second processor side 20 which is to process the task, a task number indicative of the task PT-1 ~ PT-n to be newly created and an original task number indicative of a parallelization task PT requesting task creation, task 20 creation is requested. As to other commands than the task creation, the commands will be sent according to the message shown in Fig. 3.

(2) The parallel processing unit 40P0 25 responsively activates the proxy unit 70 corresponding to the task PT-1 ~ PT-n to be created. The proxy unit 70 is activated in order to prevent management contents of

the task from being shared between the first processor side 10 and the second processor side 20 and to complete the exclusive processing on the first processor side 10. At this time, the task number of the task PT-1 ~ PT-n is 5 held in the proxy unit 70.

(3) The parallel processing unit 40P0 further sets data necessary for task creation such as the above-described task number and request contents (task creation on the processors P1 to Pn on the second processor side 20) and communication reason information 10 designating "parallel processing" at the control processing relay unit 60.

This processing results in conducting, for the control processing relay unit 60, setting of contents to 15 be communicated to the main storage device 92 (shared memory) which will be described later and processing for inter-processor interruption.

Here, communication reason information represents a recipient (acceptor) of data transferred to the 20 control processing relay unit 60 and in the above-described case, data set in the control processing relay unit 60 will be obtained by the parallel processing unit 40P1 ~ 40Pn of the designated processor P1 ~ Pn.

(4) The parallel processing unit 40P1 ~ 40Pn on 25 the designated processor P1 ~ Pn on the second processor side 20 obtains the request contents (data required for task control) having "parallel processing" as the

communication reason information from the control processing relay unit 60.

5 (5) Then, the parallel processing unit 40P1 ~ 40Pn creates and activates the task PT-1 ~ PT-n on the processor P1 ~ Pn based on the request contents obtained.

10 The foregoing processing enables a unit of work of the parallelization task PT as a unit of work of the application operating on the OS for single processors on the first processor side 10 to be parallel-processed as the task PT-1 ~ PT-n on the second processor side 20.

15 Although the foregoing operation has been described with respect to a case where the parallel processing units 40P1 to 40Pn create and activate the tasks PT-1 to PT-n on the processors P1 to Pn based on the obtained request contents, the parallelization task PT on the first processor side 10 may be created in advance as any of the tasks PT-1 to PT-n on the second processors side 20 and the parallel processing units 40P1 to 40Pn may activate the tasks PT1 to PTn on the processors P1 to Pn based on the obtained request contents.

20 Next, description will be made of OS service processing operation conducted by the OS service units 50P0 and 50P1 to 50Pn.

25 The OS service units 50P0 and 50P1 to 50Pn have a function of providing, based on a command from the tasks PT-1 to PT-n created on the processors P1 to Pn on the

second processor side 20, services related to various kinds of accesses to an external apparatus and control of the same and various kinds of accesses to a resource shared by other task and control of the same which are 5 the services by the OS30 for single processors. The main services provided by the OS30 for single processors are equivalents of a system call and an API provided by an ordinary OS.

10 Description will be made of operation of the OS service units 50P0 and 50P1 to 50Pn in response to a 15 file access (e.g. various kinds of processing with respect to a file on the external storage device 93) command from the tasks PT-1 to PT-n on the processors P1 to Pn on the second processor side 20 with reference to Fig. 4.

20 Here, file access includes such processing as open (open a file), close (close a file), read (read a file), write (write a file), seek (move a file writing position) , remove (delete a file) and rename (change a file name).

(1) When the need of file access processing arises in the tasks PT-1 to PT-n on the second processor side 20, the tasks PT1 to PTn request the OS service units 50P1 to 50Pn on the second processor side 20 to 25 provide service for file access. Called up by this file access service command, for example, are a write function defined as processing of writing to a file by

the OS service units 50P1 to 50Pn and a read function defined as file reading processing.

Here, the OS service units 50P1 to 50Pn set data necessary for the processing (file access processing by the OS30 for single processors) on the first processor side 10. Necessary data here includes such information as a request content (e.g. write request), a descriptor of a file to be accessed (file descriptor), a pointer to a character string, a length of a character string and a task number.

(2) With the communication reason information set to "OS service", by setting the necessary data containing the request contents at the control processing relay unit 60, the OS service unit 50P1 ~ 50Pn issues a file access command to the first processor side 10.

Thereafter, the task PT-1 ~ PT-n having issued the service command for file access enters a waiting state and in the corresponding processor P1 ~ Pn, processing is switched to other task by the parallel processing unit 40P1 ~ 40Pn (task switching).

(3) The OS service unit 50P0 on the first processor side 10 obtains, from the control processing relay unit 60, the above-described file access command having "OS service" as the communication reason information.

(4) The OS service unit 50P0 on the first

processor side 10 requests file access from the OS30 for single processors according to the obtained request contents.

5 (5) As a result, the OS30 for single processors makes a file access (write, read or the like) to the external storage device 93 based on the command. This file access processing is executed using the file access service without modification which the OS30 for single processors originally has.

10 (6) Upon completion of the requested file access processing, the OS30 for single processors sends a returned value for the file access command back to the OS service unit 50P0 to return the processing.

15 (7) Furthermore, the OS service unit 50P0 sets the communication content, which is data including the returned value and the task number of the task PT-1 ~ PT-n that has requested the file access, at the control processing relay unit 60 with "OS service" as the communication reason information, thereby notifying the 20 processors P1-Pn on the second processor side 20 of the completion of the file access.

25 (8) The OS service unit 50P1~50Pn of the corresponding processor P1 ~ Pn receives thus set returned value and the notification of completion from the control processing relay unit 60.

(9) Then, the OS service unit 50P1 ~ 50Pn on the second processor side 20 asks the parallel processing

unit 40P1 ~ 40Pn to activate the task PT-1 ~ PT-n which has given the file access command.

As a result, the processing switches to the task PT-1 ~ PT-n at the waiting state.

5 (10) The task PT-1 ~ PT-n activated by the parallel processing unit 40P1~ 40Pn receives the returned value of the file access from the OS service unit 50P1 ~ 50Pn to continue the processing.

10 The foregoing processing enables, without providing an individual processing unit for file access on the second processor side 20, the task PT-1 ~ PT-n on the second processor side 20 to make file access while using the service of the OS30 for single processors without modification. Also with this arrangement, 15 exclusive processing for file access is completed on the first processor side 10, so that parallel processing can be realized with no overhead caused by such exclusive processing as in operating the application on an OS for multiprocessors.

20 In a case where the task PT-1 ~ PT-n on the processor P1 ~ Pn on the second processor side 20 makes file access to read-only data on the external storage device 93, for example, direct access may be made to the external storage device 93 from each processor P1 ~ Pn 25 without such processing by the OS service unit 50P1 ~ 50Pn as described in the foregoing.

Here, as to a file access command from the

sequential task ST on the processor P0 on the first processor side 10, the processing is directly conducted by the OS30 for single processors without using the OS service unit. In the following, the processing will be 5 described with reference to Fig. 5.

(1) The sequential task ST on the processor P0 requests the OS30 for single processors to make file access.

10 (2) As a result, the OS30 for single processors conducts file access (write, read, etc.) to the external storage device 93 or the like based on the command. The file access processing is executed by using the file access service that the OS30 for single processors originally has without modification.

15 (3) When the file access processing is completed, the OS30 for single processors sends a returned value for the file access command back to the sequential task ST to return the processing.

20 Since in response to the OS service command from the sequential task ST, exclusive control and the like is unnecessary, no extra overhead will be generated.

Processing operation by the control processing relay unit 60 will be described with reference to Figs. 6 and 7.

25 First, structure of the control processing relay unit 60 is shown in Fig. 6. As illustrated in the figure, the control processing relay unit 60 includes

interruption control devices 61P0 to 61Pn corresponding to the respective processors P0 to Pn and communication regions 62P0 to 62Pn corresponding to the respective processors P0 to Pn. Here, the communication regions 62P0 to 62Pn are ensured in the main storage device 92.

5 The interruption devices 61P0 to 61Pn each further include an interruption instructing unit 61a for instructing other processor on interruption, an interruption state holding unit 61b for holding information that an interruption is made in response to an interruption instruction and an interruption canceling unit 61c for clearing an interruption.

10 The communication regions 62P0 to 62Pn each include a communication reason holding region 62a for holding communication reason information from a processor as a communication source, a communication data holding region 62b for holding communication data to be communicated and a mutual exclusive control region 62c for locking a communication region in order to 15 ensure communication.

20 At this time point, in the communication data holding region 62b, a pointer to the main storage device 92 will be stored, in which communication data to be communicated (necessary data including request contents) 25 is stored.

Operation will be described with respect to processing of communication from the parallel processing

unit 40P0 on the first processor side 10 to the processor P1 on the second processor side 20 as an example with reference to Fig. 7.

5 (1) The parallel processing unit 40P0 locks the mutual exclusive control region 62c of the communication region 62P1 for the processor P1. More specifically, by bringing a lock variable stored in the mutual exclusive control region 62c to a locked state, prevent the communication region 62P1 for the processor P1 in question from being used by other processor.

10 When the region is already locked by other processor, wait for the lock to be released.

15 (2) When the lock of the communication region 62P1 is obtained, the parallel processing unit 40P0 stores the communication reason information and the communication data (necessary data including request contents) in the communication reason holding region 62a and the communication data holding region 62b of the communication region 62P1, respectively.

20 Communication reason information to be stored is, in a case of communication processing for creating a task as described above, information indicative of "parallel processing" (e.g. data such as a numerical value predetermined corresponding to the parallel processing).

25 (3) The parallel processing unit 40P0 instructs the interruption instructing unit 61a of its own

interruption control device 61P0 to interrupt the processor P1.

(4) The interruption instructing unit 61a of the interruption control device 61P0 sets the information indicative of the interruption at the interruption state holding unit 61b of the interruption control device 61P1 corresponding to the processor P1. This brings the processor P1 to an interrupted state.

(5) The parallel processing unit 40P1 of the processor P1 determines from the state of the interruption state holding unit 61b of the interruption control device 61P1 in the control processing relay unit 60 that interruption is set.

(6) The parallel processing unit 40P1 of the processor P1 releases itself from the interrupted state by clearing the interruption information in its own interruption state holding unit 61b of the control processing relay unit 60.

(7) The parallel processing unit 40P1 of the processor P1 obtains the communication reason information and the communication data (required data including the request contents) from the communication reason holding region 62a and the communication data holding region 62b of its own communication region 62P1 in the control processing relay unit 60, respectively.

(8) Upon being allowed to receive next communication, the parallel processing unit 40P1 of the

processor P1 releases the lock of the mutual exclusive control region 62c of its own communication region 62P1. More specifically, by bringing the lock variable stored in the mutual exclusive control region 62c to the 5 unlocked state, the communication region 62P1 for the processor P1 is released so that it may be used by other processor.

Thus, using the control processing relay unit 60 realizes transmission and reception of control signals 10 and data between the first processor side 10 and the second processor side 20.

Operation of signal notification processing by the proxy unit 70 will be described with reference to Fig. 8.

15 The proxy unit 70 has a function of enabling the OS30 for single processors to communicate with the tasks PT-1 to PT-n generated on the second processor side 20 by using a signal (control signal). The task numbers of the corresponding tasks PT-1 to PT-n are held in the 20 proxy unit 70.

The proxy unit 70 may be one-to-one associated with each of the plurality of tasks PT-1 to PT-n, or the plurality of tasks PT-1 to PT-n may be associated with one proxy unit 70.

25 (1) The sequential task ST on the first processor side 10 requests signal notification service from the OS30 for single processors. The signal

communicated by the signal notification is a control signal for controlling the tasks PT-1 to PT-n activated on the respective processors P1 to Pn on the second processor side 20 by the service function which the OS30 for single processors originally has.

5 (2) The OS30 for single processors notifies the signal to the corresponding proxy unit 70.

10 (3) Through the control processing relay unit 60, the proxy unit 70 notifies the notified signal to its corresponding processor P1 ~ Pn in which the task PT-1 exists on the second processor side 20. At this point, "parallel processing" is set as the communication reason information.

15 (4) Since the communication reason information to the control processing relay unit 60 is "parallel processing", the parallel processing unit 40P1 ~ 40Pn of the corresponding processor on the second processor side 20 obtains a signal notification command from the control processing relay unit 60.

20 (5) The parallel processing unit 40P1 ~ 40Pn having obtained the signal notification command notifies the corresponding task PT-1 ~ PT-n of the signal (control signal).

25 Thus, since the proxy unit 70 is associated with the task PT-1 ~ PT-n on the processor P0 ~ Pn on the second processor side 20 by the task number, on the first processor side 10, the signal notification service

by the OS30 for single processors can be performed with respect to the tasks PT-1 to PT-n.

Lastly, inter-task cooperative operation on the second processor side 20 will be described with reference to Figs. 9 and 10.

Fig. 9 shows the structure of the parallel processing units 40P1 to 40Pn for obtaining cooperation among the tasks. As illustrated in the figure, the parallel processing units 40P1 to 40Pn are provided with mutual exclusion units 41P1 to 41Pn.

The main storage device 92 also includes a mutual exclusive control region 43 and a task management content holding region 44 to obtain task cooperation.

(1) The task PT-1 on the processor P1 requests desired parallel processing from its own parallel processing unit 40P1.

(2) The parallel processing unit 40P1 of the processor P1 requests lock acquisition from the mutual exclusion unit 41P1 in order to ensure the resources for use in parallel processing.

(3) The mutual exclusion unit 41P1 obtains the lock by using the mutual exclusive control region 43 of the main storage device 92.

(4) The mutual exclusion unit 41P1 notifies the parallel processing unit 40P1 that the lock has been obtained.

(5) The parallel processing unit 40P1 holds, in

the task management content holding region 44, the management content (request contents, task number and other required data) of the task PT-1 having requested parallel processing on the processor P1.

5 (6) The parallel processing unit 40P1 interrupts other processor P2 ~ Pn which is executing a low-priority task. Assume here that the processor Pn is interrupted.

10 (7) The parallel processing unit 40P1 asks the mutual exclusion unit 41P1 to release the lock ensured as described above.

(8) The mutual exclusion unit 41P1 unlocks the mutual exclusive control region 43 of the main storage device 92.

15 (9) The mutual exclusion unit 41P1 notifies the parallel processing unit 40P1 of the completion of the unlocking.

(10) The parallel processing unit 40P1 returns the processing to the task PT-1.

20 (11) The parallel processing unit 40Pn of the processor Pn requests lock acquisition from the mutual exclusion unit 41Pn in order to ensure the resources for use in parallel processing.

25 (12) The mutual exclusion unit 41Pn obtains the lock by using the mutual exclusive control region 43 of the main storage device 92.

(13) The mutual exclusion unit 41Pn notifies the

parallel processing unit 40Pn of the completion of the lock acquisition.

5 (14) The parallel processing unit 40Pn obtains the task management contents stored in the task management content holding region 44.

(15) The parallel processing unit 40Pn creates and activates a new task based on the task management contents.

10 (16) The parallel processing unit 40Pn requests, from the mutual exclusion unit 41Pn, release of the lock ensured as described above.

(17) The mutual exclusion unit 41Pn unlocks the mutual exclusive control region 43 of the main storage device 92.

15 (18) The mutual exclusion unit 41Pn notifies the parallel processing unit 40Pn of the completion of the unlocking.

20 Such task cooperative operation as described above allows the task PT-1 ~ PT-n activating on a certain processor P1 ~ Pn to have its own unit of work be parallel-processed by other processor.

25 As an example of applications to thus structured parallel processing system, description will be made of a case where the application is operated on a mobile terminal of a multiprocessor.

Here, the description will be made with reference to Fig. 11, assuming a case where with the application

having a function of reproducing picture (moving picture) and sound simultaneously on a mobile terminal and with sound output processing being defined as a sequential task A and picture output processing being defined as a parallelization task B, the application is 5 operated on the processor P0 on the first processor side 10.

10 The parallelization task B is created and activated as a task C on any of the processors P1 to Pn on the second processor side 20 by the above-described parallel processing unit.

The created task C outputs the picture on a screen by file access processing of the OS service unit.

15 Concerning the sound output by the sequential task A, the sound is output by the service of the OS30 for single processors.

20 For periodically synchronizing the sound and the picture, synchronization is attained by giving a signal notification between the sequential task A and the task C through the signal notification operation by the proxy unit 70.

25 In addition, when executing processing of editing the picture in the task C, the editing processing is created and activated as a task D on other processor by task cooperation processing.

When the picture output processing by the task C is completed, the task C notifies the OS for single

processors of the termination by the file access operation.

In the present embodiment, provision of the parallel processing units 40P0 to 40Pn, the OS service units 50P0 to 50Pn, the control processing relay unit 60 and the proxy unit 70 as modules enables the OS30 for single processors and the application to operate without overheads on a multiprocessor system structure without modifying the OS30 for single processors and the application operated on the processor P0, while receiving benefits from the parallel processing by the multiprocessor.

Next, a parallel processing system according to a second embodiment of the present invention will be described with reference to Fig. 12 and the drawings to follow. Fig. 12 is a block diagram showing a structure of the parallel processing system according to the second embodiment, in which components common to Fig. 1 are referenced by the same numerals. Illustrated in the second embodiment shown in Fig. 12 is a case where the parallel processing units 40P0 to 40Pn in the first embodiment are formed of parallel processing communication units 400P0 to 400Pn and control proxy units 500P0 to 500Pn, respectively.

As shown in Fig. 12, the parallel processing system according to the present embodiment is the same as the first embodiment in that a multiprocessor formed

of a plurality of processors (CPU) P0 to Pn (n is an integer not less than 1) connected through a system bus 91 is logically divided into two groups, i.e., a first processor side 100 and a second processor side 200.

5 In the second embodiment, OSes 300P0 to 300Pn for single processors are implemented which operate on the processor P0 on the first processor side 100 and the respective processors (CPU) P0 to Pn on the second processor side 200.

10 In addition, the parallel processing communication units 400P0 to 400Pn and the control proxy units 500P0 to 500Pn for parallel processing are mounted on the processor P0 on the first processor side 100 and the processors P1 to Pn on the second processor side 200, respectively. A main storage device 92 as a shared memory which is shared among the respective processors P0 to Pn and an external storage device 93 such as a disk device or the like are connected to the system bus 91.

20 Also, a control processing relay unit 600 is uniquely provided for transmitting and receiving control signals and data between the first processor side 100 and the second processor side 200.

25 Since regarding the proxy unit 70 shown in the first embodiment through which the OS 300P0 for single processors on the first processor side 100 communicates with processes executed on the second processor side 200,

the unit executes completely the same function in the present embodiment as that in the first embodiment, no description will be made here for the sake of convenience.

5 While in the first embodiment, it has been described that the switching of tasks is performed in response to a file access command from the tasks on the processors P1 to Pn on the second processor side 20, also in the present embodiment, file access from the 10 second processor side 200 is possible and switch of processes PP-1 to PPn on the second processor side 200 is conducted by the OSes 300P1 to 300Pn for single processors on the second processor side 200.

15 As to the OSes 300P0 to 300Pn for single processors mounted on the respective processors P0 to Pn, they are different from those of the first embodiment in that not only OSes having no virtual memory mechanism which realizes a memory protection function such as a real-time OS but also OSes having a virtual memory 20 mechanism such as Linux and Windows (R) as existing OSes can be used and that a memory protection mechanism can be realized on all or a part of the processors P0 to Pn.

25 In addition, the OSes 300P0 to 300Pn for single processors need not be OSes of the same kind but may be OSes of kinds different from each other.

In the present embodiment, the task, which is a unit of work for performing parallel processing, is

memory-protected between the processors and in that sense, is referred to as a process to distinguish from the task in the first embodiment.

5 In the parallel processing system according to the present embodiment, among the units of work of an application operating on the OS 300P0 for single processors on the first processor side 100, those processes which cannot be parallelized (sequential processes SP) are processed by the processor P0 on the 10 first processor side 100, and those tasks which can be parallelized within the application are created as new processes PP-1 to PP-n on the second processor side 200 and parallel-processed.

15 The parallel processing communication unit 400P0 and the parallel processing communication units 400P1 to 400Pn have the function of transmitting and receiving information related to process creation, activation, stop, termination and deletion and other control related to the processes between the processes and the OSes 20 300P0 to 300Pn for single processors.

25 Here, control information and data related to creation, activation, stop, termination, deletion or the like of tasks are transmitted and received between the first processor side 100 and the second processor side 200 through the control processing relay unit 600.

In addition, the control proxy unit 500P0 and the control proxy units 500P1 to 500Pn have the function of

obtaining a processing command from the OS 300P0 ~ 300Pn for single processors to the process and activating the process.

5 The control processing relay unit 600 is a unit for transmitting and receiving control signals and data between the first processor side 10 and the second processor side 20 and is used for controlling the plurality of processes parallel-processed by the plurality of processors.

10 In the following, operation of thus structured parallel processing system according to the second embodiment will be described in detail with reference to the drawings.

15 Assume here that the application operates on the OS 300P0 for single processors on the first processor side 100, and among the units of work of the application, a unit of work to be processed by the processor P0 on the first processor side 100 is defined as a sequential process SP, and units of work which are processes that 20 can be parallelized within the application and are parallel-processed by the second processor side 200 as the tasks PP-1 to PP-n are defined as a parallelization process PP.

25 In the second embodiment, after a certain process (task) is activated, synchronous activation of parallel processing in which the parallelization process PP as a process (task) on the calling side waits for the

termination of the activated process PP-1 ~ PP-n and asynchronous activation of parallel processing in which the parallelization process PP as a process (task) on the calling side needs not wait for the termination of 5 the activated process PP-1 ~ PP-n are both possible.

First, operation for the synchronous activation of parallel processing of a process will be described with reference to Fig. 13.

Assume here that in a processor P_k ($1 \leq k \leq n$) on 10 the second processor side 200, the parallelization process PP on the first processor side 100 is created in advance as a process PP- k which is a unit of work to be activated on the second processor side 200.

(1) The process PP- k on the processor P_k ($1 \leq k \leq n$) on the second processor side 200 registers, in a 15 parallel processing communication unit 400Pk, the information about the processing belonging to its own process. As a result, the process PP- k enters the standby state.

(2) The parallel processing communication unit 400Pk makes a request for accessing necessary data on 20 the main storage device 92 (shared memory) through an OS 300Pk for single processors.

(3) As a result, the information about the 25 processing belonging to the process PP- k is stored in the main storage device 92 (shared memory).

(4) The process PP on the processor P0 requests

synchronous processing from the parallel processing communication unit 400P0. Thereafter, the process PP enters the standby state.

5 (5) The parallel processing communication unit 400P0 having received the request makes a request to access data onto the main storage device 92 (shared memory) through the OS 300P0 for single processors.

(6) The main storage device 92 (shared memory) is accessed by the OS 300P0 for single processors.

10 (7) The parallel processing communication unit 400P0 obtains the information about processing belonging to the process PP-k from the main storage device 92 (shared memory). Thus, a processor number and a process number for executing the process PP-k are obtained.

15 (8) The parallel processing communication unit 400P0 makes a communication request based on the information obtained from the main storage device 92 (shared memory) through the OS 300P0 for single processors.

20 (9) The OS 300P0 for single processors sets the information required for communication at the control processing relay unit 600.

25 (10) As a result, the processing command is sent from the control processing relay unit 600 to the OS 300Pk for single processors of the processor Pk.

(11) The control proxy unit 500Pk of the processor Pk obtains the processing command sent through

the OS 300Pk for single processors.

(12) Then, the control proxy unit 500Pk activates the process PP-k according to the processing command obtained.

5 (13) As a result, the process PP-k at the standby state executes the processing.

(14) After finishing the processing, the process PP-k notifies the parallel processing communication unit 400Pk of the information to that effect.

10 (15) The parallel processing communication unit 400Pk having received the notification makes a communication request based on the information notified through the OS 300Pk for single processors.

15 (16) The OS 300Pk for single processors sets the information required for communication at the control processing relay unit 600.

(17) As a result, the processing command is sent from the control processing relay unit 600 to the OS 300P0 for single processors in the processor P0.

20 (18) The control proxy unit 500P0 of the processor P0 obtains the processing command sent through the OS 300P0 for single processors.

25 (19) Then, the control proxy unit 500P0 activates the process PP according to the processing command obtained.

Thus, synchronous processing is realized between the process PP on the processor P0 on the first

processor side 100 and the processor PP-k on the second processor side 200.

Next, operation for the asynchronous activation of parallel processing of a process will be described with reference to Fig. 14.

Also assume here that in the processor Pk ($1 \leq k \leq n$) on the second processor side 200, the parallelization process PP on the first processor side 100 is created in advance as the process PP-k which is a unit of work to be activated on the second processor side 200.

(1) The process PP-k which was performing the processing on the processor Pk ($1 \leq k \leq n$) on the second processor side 200 registers, in the parallel processing communication unit 400Pk, the information about the processing belonging to its own process. As a result, the process PP-k enters the standby state.

(2) The parallel processing communication unit 400Pk makes a request for accessing required data onto the main storage device 92 (shared memory) through the OS 300Pk for single processors.

(3) As a result, the information about processing belonging to the process PP-k is stored in the main storage device 92 (shared memory).

(4) The process PP on the processor P0 requests asynchronous processing from the parallel processing communication unit 400P0. In this case, the process PP thereafter continues the processing without entering the

standby state.

(5) The parallel processing communication unit 400P0 having received the request makes an access request for data on the main storage device 92 (shared memory) through the OS 300P0 for single processors.

(6) The main storage device 92 (shared memory) is accessed by the OS 300P0 for single processors.

(7) The parallel processing communication unit 400P0 obtains the information about processing belonging to the process PP-k from the main storage device 92 (shared memory). As a result, a processor number and a process number executing the process PP-k are obtained.

(8) The parallel processing communication unit 400P0 makes a communication request based on the information obtained from the main storage device 92 (shared memory) through the OS 300P0 for single processors.

(9) The OS 300P0 for single processors sets information required for communication at the control processing relay unit 600.

(10) Thus, the processing command is sent from the control processing relay unit 600 to the OS 300Pk for single processors in the processor Pk.

(11) The control proxy unit 500Pk of the processor Pk obtains the processing command sent through the OS 300Pk for single processors.

(12) The control proxy unit 500Pk then activates

the process PP-k according to the processing command obtained.

(13) Thus, the process PP-k at the standby state executes the processing.

5 In the foregoing manner, asynchronous processing is realized between the process PP on the processor P0 on the first processor side 100 and the processor PP-k on the second processor side 200.

10 The processing operation by the control processing relay unit 600 in the parallel processing system according to the second embodiment will be described with reference to Figs. 15 and 16.

15 First, structure of the control processing relay unit 600 is shown in Fig. 15. As illustrated in the figure, the control processing relay unit 600 is structured to include interruption control devices 601P0 to 601Pn corresponding to the respective processors P0 to Pn and communication regions 602P0 to 602Pn corresponding to the respective processors P0 to Pn.

20 Here, the communication regions 602P0 to 602Pn are ensured in the main storage device 92.

25 The interruption control devices 601P0 to 601Pn each have the same structure as that in the control processing relay unit 60 according to the first embodiment shown in Fig. 6 and is formed of an interruption instructing unit 601a, an interruption state holding unit 601b and an interruption canceling

unit 601c.

Also, the communication regions 602P0 to 602Pn each basically have the same structure as that in the first embodiment shown in Fig. 6 and is formed of a communication queue 602a as a combination of the communication reason holding region 62a and the communication data holding region 62b shown in Fig. 6, and a mutual exclusive control region 602c.

As an example, operation of the communication processing from the parallel processing communication unit 400P0 on the first processor side 100 to the processor Pn on the second processor side 20 will be described with reference to Fig. 16.

(1) The parallel processing communication unit 400P0 locks the mutual exclusive control region 602b of the communication region 602Pn for the processor Pn. More specifically, bring a lock variable stored in the mutual exclusive control region 602b to a locked state to prevent the communication region 602Pn for the processor Pn in question from being used by other processor.

(2) The parallel processing communication unit 400P0 stores the communication reason information and the communication data (required data including the request contents) in the communication queue 602a of the communication region 602Pn.

As the communication reason information to be

5 stored, in a case of the communication processing for process creation/activation as mentioned above, information indicative of "activation of process" (e.g. data such as a predetermined numeric value corresponding to the parallel processing) is stored.

10 (3) At the time point of (1), if the communication queue 602a of the communication region 602Pn is empty, the parallel processing communication unit 400P0 instructs the interruption instructing unit 601a of its own interruption control device 601P0 to interrupt the processor Pn.

15 (4) The parallel processing communication unit 400P0 of the processor P0 brings the mutual exclusive control region 602b of the communication region 602Pn for the processor Pn to the unlocked state. If the communication queue 602a of the communication region 602Pn is not empty at the time point of (1), the processing terminates at this point because no interruption is required.

20 (5) The interruption instructing unit 601a of the interruption control device 601P0 sets information indicative of an interruption at the interruption state holding unit 601b of the interruption control device 601Pn corresponding to the processor Pn. As a result, 25 the processor Pn enters the interrupted state.

(6) The OS 300Pn for single processors of the processor Pn accepts the interruption based on the

condition of the interruption state holding unit 601b of the interruption control device 601Pn for the processor Pn.

5 (7) The OS 300Pn for single processors in the processor Pn releases its interrupted state by clearing the interruption information of its own interruption state holding unit 601b by means of the interruption canceling unit 601c in the interruption control device 601Pn.

10 (8) The OS 300Pn for single processors in the processor Pn activates its own control proxy unit 500Pn.

(9) The control proxy unit 500Pn of the processor Pn sets a lock at the mutual exclusive control region 602b of its own communication region 602Pn.

15 (10) The control proxy unit 500Pn of the processor Pn further deletes the communication reason information and the communication data from the communication queue 602a of its own communication region 602Pn.

20 (11) The control proxy unit 500Pn of the processor Pn unlocks the mutual exclusive control region 602b of the communication region 602Pn for the processor Pn. This makes the communication region 602Pn for the processor Pn be unusable by other processor.

25 Thus, by using the control processing relay unit 600, transmission and reception of control signals and data between the first processor 100 and the second

processor 200 are realized.

Next, a parallel processing system according to a third embodiment of the present invention will be described in the following with reference to Fig. 17.

5 Fig. 17 is a block diagram showing a structure of the parallel processing system according to the third embodiment, in which components common to those in Fig. 13 are referenced by the same numerals.

10 In the above-described synchronous processing in the second embodiment, it is necessary to repeat checking whether between processes, one process has its data on the main storage device 92 updated by other process, resulting in involving extra processing as much as the repetition, while the present embodiment enables 15 high-performance synchronization and data transmission and reception between processes which requires none of such extra processing.

As shown in Fig. 17, the parallel processing system according to the present embodiment includes, 20 similarly to the second embodiment, a multiprocessor composed of a plurality of processors (CPU) P0 to Pn (n is an integer not less than 1) connected through a system bus 91 which is logically divided into two groups of a first processor side 100 and a second processor side 200, with OSes 300P0 to 300Pn for single processors mounted which operate on the processor P0 on the first processor side 100 and the processors (CPU) P1 to Pn on

the second processor side 200.

The third embodiment is characterized in further including, in addition to the parallel processing communication units 400P0 ~ 400Pn for conducting parallel processing of the processor P0 on the first processor side 100 and the processors P1 to Pn on the second processor side 200 and the control proxy units 500P0 to 500Pn, inter-process communication units 1000P0 to 1000Pn for realizing communication between the respective processes executed on the processor P0 on the first processor side 100 and on the processors P1 to Pn on the second processor side 200.

In other words, the present embodiment enables the inter-process communication function which is conventionally mounted on an OS for multiprocessors to be realized on a parallel processing system by an OS for single processors which operates an OS for single processors and an application on a multiprocessor, thereby enabling an inter-process communication function to be provided on a user-level.

Since also in the present embodiment, the proxy unit 70 by which the OS 300P0 for single processors on the first processor side 100 communicates with a process to be executed on the second processor side 200 as shown in the first embodiment executes completely the same function as that in the first embodiment, no description will be made thereof for the sake of convenience.

Since structure and operation of other components than the above-described inter-process communication units 1000P0 to 1000Pn are completely the same as those described above in the second embodiment, description 5 will be made only of the inter-process communication units 1000P0 to 1000Pn.

The inter-process communication units 1000P0 to 1000Pn realize communication between the processes executed on the processors P1 to Pn by using such system 10 as a semaphore or a message queue.

Description will be made here with respect to a case where the inter-process units 1000P0 to 1000Pn conduct inter-process communication using the semaphore system.

15 As illustrated in Fig. 18, description will be made of a case where when a process PP-m and a process PP-n are executed on a processor Pm and a processor Pn on the second processor side 200, respectively, the process PP-m and the process PP-n communicate by using 20 the semaphore system by means of inter-process communication units 1000Pm and 1000Pn.

25 Semaphore is a system for a plurality of processes to communicate and synchronize with each other on a multi-task OS on which a plurality of processes are simultaneously executed and is a kind of shared flag (counter) to which processes to be synchronized with each other pay attention to conduct processing according

to a change of the counter, thereby realizing communication (synchronization).

First, with reference to Fig. 18, description will be made of operation of the process PP-m on the processor Pm of upping or downing a semaphore information region (shared flag) of the main storage device 92. Assume here that semaphore-up is to increment a counter value of the semaphore information region and semaphore-down is to decrement the counter value of the semaphore information. When semaphore-down is not allowed, the process in question sleeps to enter a waiting state and is waked up by semaphore-up.

(1) When the process PP-m on the processor Pm ups or downs the semaphore (semaphore counter), it makes a request to that effect to the inter-process communication unit 1000Pm.

(2) The inter-process communication unit 1000Pm having received the request accesses a semaphore information region #N (as many semaphore information regions as a number predetermined by the system are ensured) as a shared flag distinguishable by a semaphore number ensured in the main storage device 92 to determine whether the semaphore can be upped or downed.

Next, with reference to Fig. 19, description will be made of a case where the process PP-m on the processor Pm downs the semaphore (semaphore flag).

(1) The process PP-m on the processor Pm

requests the inter-process communication unit 1000Pm to down the semaphore (semaphore flag).

(2) The inter-process communication unit 1000Pm having received the request accesses the semaphore 5 information region #N ensured in the main storage device 92. Here, an initial value "0" is set at the semaphore information region #N as a counter value of the semaphore and is fixed not to be downed in advance even trying. It is therefore determined that the semaphore 10 can not be downed.

(3) The inter-process communication unit 1000Pm requests the OS 300Pm for single processors to make the process PP-m sleep by using a system call.

(4) The OS 300Pm for single processors makes the process PP-m sleep by using the system call to take out 15 the same from a run queue.

In other words, being not allowed to down the semaphore in the above-described case, the process PP-m sleeps.

20 Moreover, with reference to Fig. 20, description will be made of operation executed when with the process PP-m sleeping as described above, a process PP-m1 on the same processor Pm ups the semaphore.

(1) The process PP-m1 requests the inter-process 25 communication unit 1000Pm to up the semaphore.

(2) The inter-process communication unit 1000Pm accesses the semaphore information region #N ensured in

the main storage device 92 to determine that there exists the process PP-m waiting for semaphore.

5 (3) The inter-process communication unit 1000Pm further transmits a message (control message) to a control processing relay unit 600 to request wake-up of the process PP-m.

10 (4) The control proxy unit 500Pm receives the message from the control processing relay unit 600. Message relay by the control processing relay unit 600 is conducted based on the operation described with reference to Figs. 15 and 16.

15 (5) The control proxy unit 500Pm determines from the message that the request is made for wake-up of a process waiting for semaphore to give the OS 300Pm for single processors a request for waking up the process PP-m at a waiting state by using a system call.

20 (6) The OS 300Pm for single processors wakes up the requested process PP-m by using the system call to connect the same to a run queue. In this case, the waked-up process PP-m again tries to down the semaphore.

25 Requesting wake-up of the process PP-m directly from the inter-process communication unit 1000Pm to the control proxy unit 500Pm by using the communication function of the OS 300Pm for single processors without using control message relay by means of the control processing relay unit 600 as described in the processing (3) and (4) set forth above leads to elimination of the

processing (3) and (4) to enable high-speed processing.

With reference to Fig. 21, description will be made of operation conducted in a case where with the process PP-m on the processor Pm sleeping as described above, the process PP-n on other processor Pn ups the semaphore.

(1) The process PP-n on the processor Pn requests semaphore-up from the inter-process communication unit 1000Pn of its own processor Pn.

(2) The inter-process communication unit 1000Pn accesses the semaphore information region #N ensured in the main storage device 92 to determine that there exists the process PP-m waiting for semaphore.

(3) The inter-process communication unit 1000Pn further transmits a message (control message) to the control processing relay unit 600 to request wake-up of the process PP-m.

(4) Subsequently, the control proxy unit 500Pm of the processor Pm receives the message from the control processing relay unit 600. Message relay by the control processing relay unit 600 is conducted based on the operation described with reference to Figs. 15 and 16.

(5) The control proxy unit 500Pm determines from the message that the request is made for wake-up of a process waiting for semaphore to give the OS 300Pm for single processors a request for waking up the process

PP-m at the waiting state by using a system call.

(6) The OS 300Pm for single processors wakes up the requested process PP-m by using the system call to connect the same to a run queue. In this case, the waked up process PP-m again tries to down the semaphore.

Next, as shown in Fig. 22, description will be made of a case where with the process PP-m and the process PP-n being executed on the processor Pm and the processor Pn on the second processor side 200, the process PP-m and the process PP-n communicate with each other by using a message queue system by means of the inter-process communication units 1000Pm and 1000Pn.

Message queue system, which is a communication method between a plurality of processes, is a system of creating a "queue" as literally indicated in the name and storing a message (processed data transmitted and received between processes) as information in the queue. In the message queue system, a receiver side process is allowed to receive the message in an arbitrary order. When any of the processes receives the message, the message will disappear from the queue.

With reference to Fig. 22, description will be made of a case where the process PP-m on the processor Pm receives a message by using the message queue system. In this case, a message to be obtained exists in a queue information region #N (as many queue information regions as a predetermined number are ensured) distinguishable

by a queue number ensured in the main storage device 92.

(1) In order to receive a message, the process PP-m on the processor Pm requests the reception from the inter-process communication unit 1000Pm.

5 (2) The inter-process communication unit 1000Pm having received the request accesses the queue information region #N ensured in the main storage device 92 to receive the message.

10 (3) Then, the inter-process communication unit 1000Pm copies the received message onto the requesting source process PP-m. At this point, the message in question is erased from the queue information region #N ensured in the main storage device 92.

15 Next, with reference to Fig. 23, description will be made of second operation executed when the process PP-m on the processor Pm receives a message by the message queue system. In this case, a message to be obtained fails to exist in the queue information region #N ensured in the main storage device 92.

20 (1) In order to receive a message, the process PP-m on the processor Pm makes a request to that effect to the inter-process communication unit 1000Pm.

25 (2) The inter-process communication unit 1000Pm having received the request accesses the queue information region #N ensured in the main storage device 92. In this case, determination is made that the message to be obtained fails to exist in the ensured queue

information region #N to disable reception of the message.

5 (3) The inter-process communication unit 1000Pm requests the OS 300Pm for single processors to make the process PP-m sleep by using a system call.

(4) The OS 300Pm for single processors makes the process PP-m sleep by using the system call to disconnect the same from the run queue.

10 In other words, the process PP-m is not allowed to receive the message, so that it sleeps in the above-described case.

15 With reference to Fig. 24, description will be made of operation executed when the process PP-m on the processor Pm transmits a message by the message queue system. In this case, no process exists which is waiting for a message to be transmitted and only the message transmission to the queue information region #N ensured in the main storage device 92 is conducted.

20 (1) In order to transmit a message, the process PP-m on the processor Pm makes a request to that effect to the inter-process communication unit 1000Pm.

25 (2) The inter-process communication unit 1000Pm having received the request accesses the queue information region #N ensured in the main storage device 92 to store the message from the process PP-m.

Description will be further made of operation executed when a process on the processor Pm transmits a

message by the message queue system as shown in Fig. 25. In this case, there exists a process waiting for a message to be transmitted. In other words, this is a case where with the process PP-m being unable to receive 5 a message and sleeping, a message is sent from a process PP-m1 as shown in the example in Fig. 23.

(1) The process PP-m1 requests message transmission from the inter-process communication unit 1000Pm.

10 (2) The inter-process communication unit 1000Pm accesses the queue information region #N ensured in the main storage device 92 to store the message from the process PP-m1. Here, determination is made that there exists the process PP-m waiting for a message.

15 (3) The inter-process communication unit 1000Pm further transmits a control message to the control processing relay unit 600 to request wake-up of the process PP-m.

20 (4) The control proxy unit 500Pm receives the control message from the control processing relay unit 600.

25 (5) The control proxy unit 500Pm determines from the control message that the command is for waking up a process waiting for a message and requests the OS 300Pm for single processors to wake up the above-described process PP-m at the waiting state by using a system call.

(6) The OS 300Pm for single processors wakes up

the requested process PP-m by using the system call to connect the same to the run queue.

5 In this case, the waked up process PP-m again tries to receive the message. As a result, the message from the process PP-m1 is received by the process PP-m.

10 Requesting wake-up of the process PP-m directly from the inter-process communication unit 1000Pm to the control proxy unit 500Pm by using the communication function of the OS 300Pm for single processors without using control message relay by the control processing relay unit 600 as shown in the above-described processing (3) and (4) leads to elimination of the processing (3) and (4) to enable high-speed processing.

15 With reference to Fig. 26, description will be made of operation conducted in a case where with the process PP-m on the processor Pm sleeping to wait for a message, the process PP-n on other processor Pn transmits a message as shown in Fig. 23.

20 (1) The process PP-n on the processor Pn requests the inter-process communication unit 1000Pn of its own processor Pn to transit a message.

25 (2) The inter-process communication unit 1000Pn accesses the queue information region #N ensured in the main storage device 92 to store the message from the process PP-n. It is determined here that there exists the process PP-m waiting for a message.

(3) The inter-process communication unit 1000Pn

further transmits a control message to the control processing relay unit 600 to request wake-up of the process PP-m.

5 (4) Subsequently, the control proxy unit 500Pm of the processor Pm receives the control message from the control processing relay unit 600.

10 (5) The control proxy unit 500Pm determines from the control message that the command is for waking up a process waiting for a message and gives the OS 300Pm for single processors a request for waking up the above-described process PP-m at the waiting state by using a system call.

15 (6) The OS 300Pm for single processors wakes up the requested process PP-m by using the system call to connect the same to a run queue.

20 In this case, the waked up process PP-m again tries to receive the message. As a result, the message from the process PP-n is received by the process PP-m to execute inter-process communication between different processors.

25 According to the present embodiment, process control such as process switching and data transmission and reception are enabled by communication between processes (synchronization or message transmission and reception) within the same processor or between different processors by the inter-process communication units 1000P0 to Pn by using the semaphore system or the

message queue system in the manner as described in the foregoing.

Although inter-process communication by an OS for single processors is conducted limitedly between processes in the same processor and inter-process communication between different processors should be conducted by using a network having heavy processing loads or the like, using the semaphore system and the message queue system by the control processing relay unit 600 and the inter-process communication units 1000P0 to Pn whose processing speed is faster than that of network communication realizes inter-process communication having a high processing speed also in a multiprocessor system mounted with an OS for single processors.

As to inter-process communication within the same processor, substantially equivalent performance can be obtained to the processing performance required from sleep to wake-up of a process by an OS for single processors.

A further advantage is that unlike an OS for multiprocessors, even mounted with an OS for single processors varying with each processor, inter-process communication between processors is possible.

Next, description will be made of a specific example of the above-described inter-process communication by using the semaphore system and the

message queue system by means of the inter-process communication units 1000P0 to 1000P with reference to Fig. 27.

In Fig. 27, the process PP-0, a process PP-j and a process PP-k are executed on the processor P0, a processor Pj and a processor Pk, respectively. Here, the process PP-0 operates as a browser, the process PP-j as a java applet and the process PP-k as an MPEG4 application and as illustrated in Fig. 28, within a window embedded in a browser 1100 by the process PP-0, java applet contents 1200 by the process PP-j and MPEG4 picture contents 1300 by the process PP-k are displayed in synchronization with each other.

In this example, among the units of work of the application operating on the OS 300P0 for single processors on the first processor side 100, the process PP-0 is operated on the processor P0 and the process PP-j and the process PP-k, the processes which can be parallelized within the application, are parallel-processed in the processor Pj and the processor Pk on the second processor side 200.

In Fig. 27, when the java applet (process PP-j) and the MEPG4 application (process PP-k) are activated, both wait for reception of java appli-data and MPEG4 picture data from the browser (process PP-0) (Steps S101 and S201).

Here, from the process PP-0 of the processor P0,

by using message transmission by means of the inter-process communication unit 1000P0, the java appli-data and the MPEG4 picture data are transmitted as a message and received by the java applet (process PP-j) and the
5 MPEG4 application (process PP-k).

As a result, operation by the java applet (process PP-j) is started (Step S102) to start decoding processing by the MPEG4 application (process PP-k) (Step S202).

10 In this example, since it is clear in advance that operation by the java applet (process PP-j) ends earlier than the decoding processing by the MPEG4 application (process PP-k), the initial value of the semaphore counter is set to "0" such that after
15 finishing the operation, the java applet (process PP-j) waits for completion of the processing by the MPEG4 application (process PP-k), thereby preventing the java applet (process PP-j) having finished the operation earlier from downing the semaphore. In addition, the
20 MPEG4 application (process PP-k) is defined to up the semaphore after finishing the processing.

Although the java applet (process PP-j) tries to down the semaphore (Step S103), it can not down the same because the initial value of the counter is "0", so that
25 it sleeps to wait for semaphore.

When the MPEG4 application (process PP-k) ends the processing (Step S203), it requests semaphore-up

(Step S204). As a result, the java applet (process PP-j) waiting for semaphore is waked up and allowed to down semaphore.

Repeating the foregoing operation for each frame
5 results in displaying the contents 1200 of the java applet by the process PP-j and the MEPG4 picture contents 1300 by the process PP-k in synchronization with each other within the window embedded in the browser 1100 by the process PP-0.

10 Next, a parallel processing system according to a fourth embodiment of the present invention will be described with reference to Fig. 29. Fig. 29 is a block diagram showing a structure of the parallel processing system according to the fourth embodiment, in which
15 components common to those in Fig 13 are referenced by the same numerals.

As shown in Fig. 29, the parallel processing system according to the fourth embodiment includes a multiprocessor composed of a plurality of processors
20 (CPU) P1 ~ Pn (n is an integer not less than 2) connected through a system bus 91, which are mounted with OSes 300P1 to 300Pn for single processors operating on the respective processors P1 to Pn.

More specifically, the present embodiment differs
25 from the first to third embodiments in that the multiprocessor is not logically divided into two groups, the first processor side and the second processor side.

The fourth embodiment, similar to the above-described third embodiment, is characterized in further including, in addition to parallel processing communication units 400P1 to 400Pn for conducting 5 parallel processing of the processors P1 to Pn and control proxy units 500P1 to 500Pn, inter-process communication units 1000P1 to 1000Pn for realizing communication between the respective processes executed on the processors P1 to Pn.

10 On the other hand, process control on each of the processors P1 to Pn is possible without having the OS service units 50P1 to 50Pn as provided in the first embodiment and the parallel processing communication units 400P1 to 400Pn as provided in the first to third 15 embodiments. The OSes 300P1 to 300Pn for single processors on the respective processors P1 to Pn need not to be the same OS but to be different from each other.

20 In other words, the present embodiment as well enables the inter-process communication function which is conventionally mounted on an OS for multiprocessors to be realized on a parallel processing system by an OS for single processors which operates an OS for single processors and an application on a multiprocessor, 25 thereby enabling an inter-process communication function to be provided on a user-level.

Execution of each process in each of the

processors P1 to Pn is conducted without requiring exclusive control with other processor

Inter-process communication within an individual processor P1 - Pn and inter-process communication between the processors are conducted, as described in the third embodiment, by using the semaphore system and the message queue system by means of the inter-process communication units 1000P1 to 1000Pn to execute synchronization processing and data transmission and reception between the processes.

In addition, the above-described parallel processing system according to the respective embodiments can be realized by a parallel processing program having the respective functions of the parallel processing unit, the OS service unit, the control processing relay unit, the proxy unit and the inter-process communication unit. The parallel processing program is stored in a magnetic disk, a semiconductor memory or other storage medium, and loaded from the storage medium onto a computer processing device to control the operation of the computer processing device, thereby realizing the above-described respective functions.

Although the present invention has been described with respect to the preferred embodiments and operation examples in the foregoing, the present invention is not limited to the above-mentioned and may be implemented in

variations within the scope of its technical idea.

According to the present invention, as described in the foregoing, by operating an OS for single processors and an existing application on a multiprocessor without modifying them, parallel processing by the multiprocessor can be realized with respect to the application.

Moreover, according to the present invention, implementing the parallel processing unit, the OS service unit, the control processing relay unit and the proxy unit as modules enables an OS for single processors and an existing application to operate with no overheads on a multiprocessor system structure without modifying an application executed on the OS for single processors, as well as receiving benefits from parallel processing by the multiprocessor.

Furthermore, without providing an individual processing unit for file access on the second processor side, the tasks on the second processor side are allowed to make file access by using the services of the OS for single processors without modifying them. In addition, this enables exclusive processing for file access to be completed on the first processor side, so that parallel processing can be realized without causing overheads due to exclusive processing as in a case of operating an application on an OS for multiprocessors.

Moreover, by mounting an OS for single processors

having a virtual memory mechanism on the processor on the first processor side and on each processor on the second processor side, the above-described parallel processing can be realized while conducting memory protection between the processes.

Furthermore, when either one or both of a unit of work (task/process) on the first processor side and a unit of work on the second processor side request processing from the parallel processing unit, the parallel processing unit or the OS for single processors on the second processor side brings the requesting source unit of work to the standby state, thereby realizing synchronous processing.

Moreover, when either one or both of the unit of work (task/process) on the first processor side and the unit of work on the second processor side request processing from the parallel processing unit, the parallel processing unit or the OS for single processors on the second processor side continues execution of the requesting source unit of work, thereby realizing asynchronous processing.

In addition, mounting an inter-process communication function on a user-level enables communication between processes in parallel processors also on an OS for single processors without requiring an OS for multiprocessors.

Further advantage is that unlike an OS for

multiprocessors, inter-process communication is possible between processors even when each processor is mounted with a different OS for single processors.

Although the invention has been illustrated and 5 described with respect to exemplary embodiment thereof, it should be understood by those skilled in the art that the foregoing and various other changes, omissions and additions may be made therein and thereto, without departing from the spirit and scope of the present 10 invention. Therefore, the present invention should not be understood as limited to the specific embodiment set out above but to include all possible embodiments which can be embodies within a scope encompassed and 15 equivalents thereof with respect to the feature set out in the appended claims.